DEC 1 0 1985 375 COMPLETED 16 A1.36:1722

United States Department of Agriculture

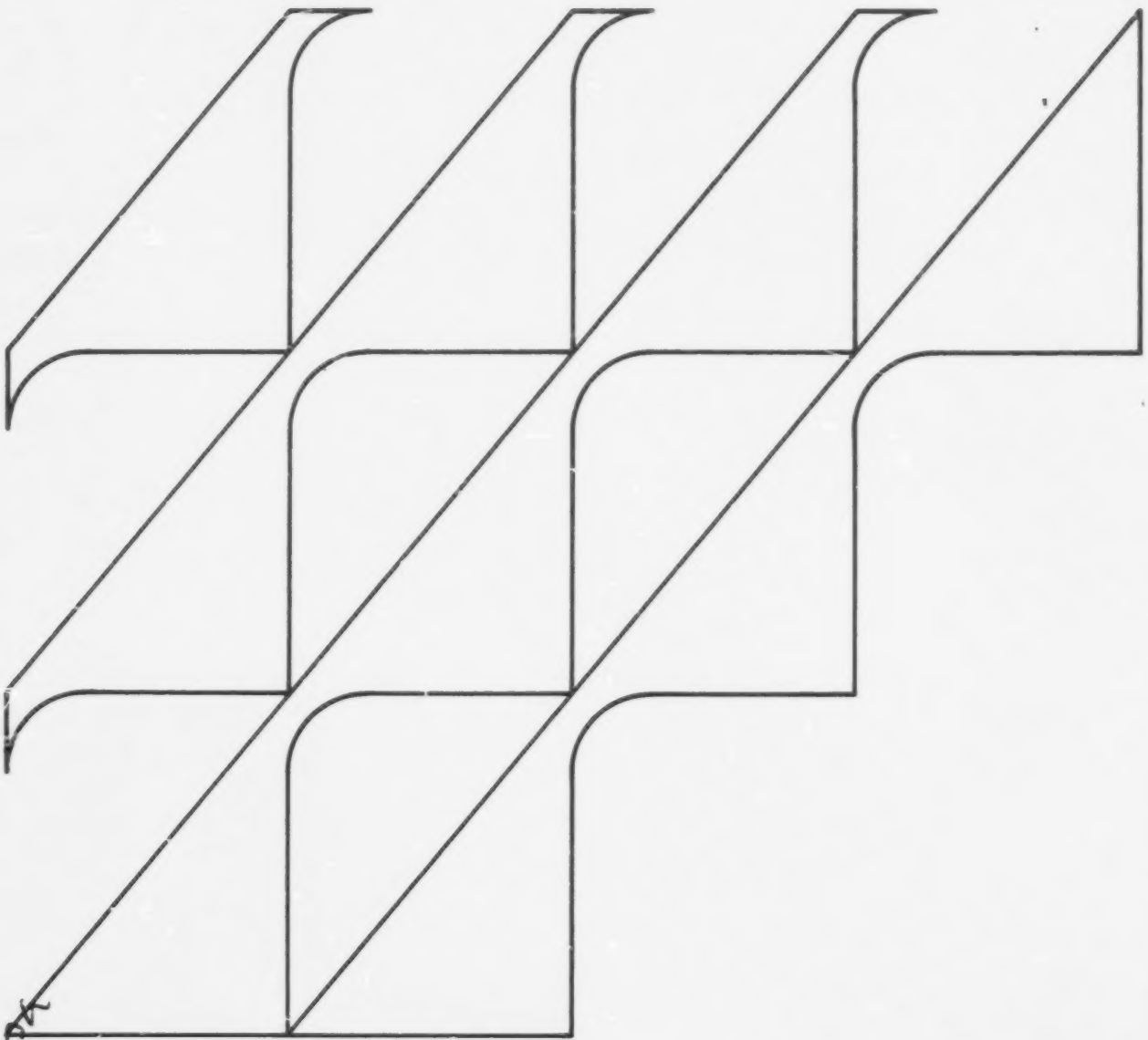
Economic Research Service

Technical Bulletin Number 1722

Effects of Changes in U.S. Agricultural Production on Demand for Farm Inputs

Robbin Shoemaker

ORIGINAL



I

BEST COPY AVAILABLE.

BLANK PAGE

EFFECTS OF CHANGES IN U.S. AGRICULTURAL PRODUCTION ON DEMAND FOR FARM INPUTS. By Robbin Shoemaker, Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Technical Bulletin No. 1722.

ABSTRACT

The economic concept of constant returns to scale (CRS) may be too restrictive to give an accurate description of the agricultural sector. CRS assumes that a change in the level of agricultural production yields an equivalent change in the level of all inputs (such as farm machinery, labor, energy, land). The model used here, however, demonstrates that demand varies more for some farm inputs than others with changes in farm output, input prices, and technology, and that this effect can be calculated. The model uses a decomposition technique to show the effects of each of those changes individually on farm inputs.

Keywords: Constant returns to scale, agricultural output, input prices, technical change, decomposition analysis

Additional Copies of this Report...

May be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Include the title and series number in your order. Write to the above address for price information or call the GPO order desk at (202) 783-3238. You may charge your purchases by telephone to your VISA, MasterCard, Choice, or GPO Deposit Account. Bulk discounts available.

Microfiche copies ($5.95 each) can be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Include the title and series number in your order. Enclose a check or money order payable to NTIS; add $3 for handling for each order. For faster service, call NTIS at (703) 487-4650 and charge your purchase to your VISA, MasterCard, American Express, or NTIS Deposit Account. NTIS will ship rush orders within 24 hours for an extra $10; call 800-336-4700.

The Economic Research Service has no copies for free distribution.

Washington, DC 20005-4788 November 1986

BEST COPY AVAILABLE

CONTENTS

	Page
SUMMARY	iv
INTRODUCTION	1
HOMOTHETICITY AND RELATIVE FACTOR DEMAND	1
ESTIMATION AND RESULTS	5
DECOMPOSITION OF RELATIVE FACTOR DEMAND	9
IMPLICATIONS	11
REFERENCES	13
APPENDIX TABLE	15

SUMMARY

"Constant returns to scale" (CRS) is an economic concept that assumes that a change in the level of agricultural production, or output, yields an equivalent change in the level of all inputs (such as farm machinery, labor, and energy). This report finds that concept is too restrictive, that the relative demand for inputs varies with the level of output, and that this effect can be calculated.

Using a decomposition analysis (a technique that isolates the components of change), the study demonstrates how three individual effects--output (production), input prices, and technical change--can be isolated so that agricultural analysts can see their specific contribution to the demand for inputs like land, labor, and machinery.

The analysis suggests that production increases (decreases) will increase (reduce) the demand for farm machinery relative to labor and will increase (reduce) the demand for energy and materials (such as fertilizer and pesticides) relative to land.

Knowing how a change in agricultural output affects demand for agricultural inputs may be useful in formulating farm programs. Policymakers have attempted to reduce the oversupply of agricultural products, assuming that to be a primary source of low farm prices. Studies examining the relationship between various farm inputs and outputs often assume farm production is characterized by CRS, which maintains that a decrease in output directly reflects the total decrease in inputs. Not only have analysts assumed that a change in agricultural production yields an equivalent change in agricultural inputs, but they have further assumed that the changes among these inputs are equiproportionate; that is, a 10-percent decrease in output would indicate a 10-percent decrease in <u>each</u> input.

BEST COPY AVAILABLE

Effects of Changes in U.S. Agricultural Production on Demand for Farm Inputs

Robbin Shoemaker

INTRODUCTION

What effect does a change in agricultural output have on the demand for agricultural inputs? In this report, I examine the implication of supply control programs for the relative demand for farm production inputs. Policymakers have attempted, for example, to reduce the supply of agricultural products because they have assumed that an oversupply of agricultural products relative to their demand is a primary source of persistently low farm prices.

I discuss the theoretical implications of relative output effects and apply them to an empirical model of U.S. agricultural production using translog factor share equations. This analysis is particularly relevant to U.S. agriculture in the postwar period because of the almost continual expansion of output associated with increased capital intensity (15).[1/] The main contributions of my study are: (1) to expand on a decomposition technique developed by Kako (7), (2) to use this technique to isolate the nonneutral effects of output, relative input price changes, and technological progress, and (3) to indicate the contribution of these effects to the relative demand for inputs.

I examine the theoretical implications of constant returns to scale (CRS), or homotheticity, for production and cost functions. I then discuss the estimation procedures and the empirical results. Finally, I perform a decomposition analysis, a technique that isolates the components of change, and suggest some policy implications. In addition to the effects of substitution and technical change, the level of output plays a significant role in determining the relative demand for inputs.

HOMOTHETICITY AND RELATIVE FACTOR DEMAND

The issue of whether output significantly alters the relative demand for inputs centers on assumptions about the production function. CRS typically is assumed for aggregate production where an increase in output is associated with equiproportionate increases in all inputs. This structural relationship of inputs and outputs is assumed for two reasons.

1/ Underscored numbers in parentheses refer to items in the References at the end of this report.

BEST COPY AVAILABLE

First, by assuming CRS or linear homogeneity, one can invoke Eulers theorem so that the sum of marginal value products of each factor times that factor equals the total value of output.[2/] This assumption is the basis for the national or sectoral income accounting identity; that is, value-added output less capital consumption and indirect business taxes is equal to the sum of all factor payments in national income. Jorgenson and Griliches (6) used this approach in their earlier productivity studies.

Second, under the condition of perfect competition, output price equals marginal cost and the minimum of longrun average cost, which is the point on the average cost curve reflecting CRS. At this point, there are zero profits and the firm is in longrun equilibrium. The existence of nonzero profits implies disequilibrium resulting from too few or too many firms or from some noncompetitive behavior (for example, monopoly power), which yields rents to a certain factor input. Another reason CRS is assumed is simply that, although a tractable assumption, it allows for greater degrees of freedom in econometric work by requiring fewer parameters to be estimated than if nonconstant returns to scale were assumed.

Although the assumption of CRS has been criticized because of the possible bias in total factor productivity estimation (13, 16), it also imposes severe limitations regarding the behavior of factor demands (17). As is well known, production functions that exhibit CRS or linear homogeneity are a subset of a more general class of functions termed homothetic functions. Because of this relationship between homothetic and linear homogeneous functions, statistical tests that reject homotheticity are sufficient for rejecting CRS. Homothetic functions are monotonic transformations of homogeneous functions. Graphically, this monotonicity implies that the production isoquants are all radial expansions of one another, thus implying that any ray through the origin will coincide with constant marginal rates of technical substitution (MRTS). Constant MRTS is equivalent to having a linear expansion path with a constant input price ratio, which further implies that relative input demands are independent at the level of output.

Another way to express this concept is to say that, under homotheticity, output elasticities are equal for all factors. To see this equality, consider the following expression where x and y are inputs and output, respectively:

$$\partial(x_i/x_j)/\partial y = 0 \qquad (1)$$

which yields:

$$(\partial x_i/\partial y)(y/x_i) - (\partial x_j/\partial y)(y/x_j) = 0 \qquad (2)$$

or $E_{iy} = E_{jy}$, where E_{iy} is the x_i output elasticity. Because $E_{iy} > 0$ implies x_i is a normal good and $E_{iy} < 0$ implies x_i is an inferior good, if all E_{iy} are equal, they must all be normal goods. Therefore, by assuming a homothetic production technology, one disallows the possibility of inferior inputs. Although the notion of inferior inputs may be somewhat troublesome,

---

2/ Note that, if the production function is homogeneous of degree $r \neq 1$, total factor payments will not equal the value of total product, and there will be either economic rents or losses. The latter case, for example, may be the result of a Government price policy that causes a difference between the actual and competitive price outcomes.

BEST COPY AVAILABLE

it is not precluded by production theory. Furthermore, the imposition of equal rates of factor demand with respect to output seems far too restrictive in light of apparent structural change in agricultural production. Because the sum of x_i output elasticities equals the elasticity of scale, it should be intuitively obvious that, if the production function is characterized by a linear expansion path, the elasticity of factor demand with respect to output is equal to the elasticity of scale.

The bottom line to this discussion is that, if we accept CRS, we must also accept equal factor-output elasticities. If that concept is too restrictive, we must reconsider our CRS assumption. The duality between production and cost functions permits us to test empirically for the existence of a homothetic production technology with a cost function.[3/] If we assume there is an aggregate production function for U.S. agriculture, then there is a corresponding dual-cost function reflecting the production technology. Expressed in its general form, the cost function is written as $C = C(Y,w,T)$, where C is total cost, Y is the level of output, w is a vector of input prices, and T represents the level of technology or technical progress. Linear homogeneity, or (even more generally) homotheticity of the production function, implies the cost function is separable in output and input prices. For the cost function, separability implies that costs are expressed as:

$$C = h(Y)C(w) \tag{3}$$

Employing Shephard's lemma and the definition of homotheticity implies:

$$\frac{\partial C/\partial w_i}{\partial C/\partial w_j} = \frac{h(Y)\partial C(w)/\partial w_i}{h(Y)\partial C(w)/\partial w_j} = \frac{x_i}{x_j} \tag{4}$$

The output terms cancel, indicating output is independent of constant relative input prices. Finally, homotheticity implies that the elasticity of scale is independent of input prices. For agriculture, separability between output and input prices would imply that production expansion in the aggregate is not constrained by relative factor prices.

To determine the possible effect that output may have on factor demands, we must first test for the existence of a homothetic production technology. By estimating a system of translog factor-cost share equations, one can test various restrictions on the production technology. Using Shephard's lemma, one can derive the translog share equations from the cost function as:

$$\frac{\partial \log C}{\partial \log w_i} = \frac{x_i w_i}{\Sigma_i x_i w_i} = S_i = a_i + \Sigma_j b_{ij} \log w_j + b_{iy} \log Y + b_{it} T \tag{5}$$

where S_i is the i^{th} factor cost share, Y and w are output and input prices, respectively, and T is a time trend representing the level of technical progress.[4/]

3/ The cost function is used because the resulting input demand functions are Hicksian compensated demands or output conditional demands and as such permit readily calculable output effects. A profit function approach could be used which yields ordinary Marshallian demands. The output effects in this case are not readily derived, but can be found with the method Lopez discusses (10).

4/ Using a time trend as a proxy for technical progress is often criticized, although to date no sufficient measure of aggregate exogenous technical progress exists.

BEST COPY AVAILABLE

Linear homogeneity in factor prices implies:

$$\Sigma_i a_i = 1; \quad \Sigma_i b_{ij} = \Sigma_i b_{ij} = \Sigma_i b_{iy} = \Sigma_i b_{it} = 0 \tag{6}$$

and symmetry implies $b_{ij} = b_{ji}$. Binswanger (4) calculates the Allen partial elasticities of substitution (AES) as:

$$\sigma_{ii} = \frac{b_{ii}}{S_i} + 1 - \frac{1}{S_i} \tag{7a}$$

$$\sigma_{ij} = \frac{b_{ij}}{S_i S_j} + 1 \tag{7b}$$

The own- and cross-price elasticities are calculated as:

$$\eta_{ii} = \sigma_{ii} S_i \tag{8a}$$

$$\eta_{ij} = \sigma_{ij} S_i \tag{8b}$$

Homotheticity implies the cost function is separable in output (y) and input prices (w); therefore, homotheticity restrictions for the translog share equations are:

$$b_{iy} = 0, \quad \forall_i \tag{9}$$

Rejecting homotheticity is sufficient for rejecting homogeneity in output of any degree. If homotheticity is rejected, normality or inferiority of a factor could be determined as the partial derivative of the i^{th} factor with respect to output. Because we are estimating share equations, we use the definition of nonhomotheticity to determine the change in relative factor shares with output or scale bias effects. That is:

$$S_{ij} = \frac{\partial (S_i/S_j)}{\partial \log Y} = \frac{b_{iy}}{S_i} - \frac{b_{jy}}{S_j} \gtrless 0 \tag{10}$$

For S_{ij} greater than zero, the technology uses more of factor s_i relative to s_j with expansions in output. Conversely, the given technology uses less of S_i relative to S_j with output growth if $S_{ij} < 0$. $S_{ij} = 0$ implies constant factor proportions of S_i and S_j with output. Note that these bias measures are symmetrical but negative; that is, $S_{ij} = -S_{ji}$.

This definition of homotheticity is quite similar to the classical definition of Hicks' neutral technical change. Hicks defined neutral technical change as a constancy of factor ratios before and after the introduction of a technical innovation. This form of technical change also implies a linear inward shift of production isoquants with technical change in the same fashion as a homothetic shift along a linear expansion path. Because Hicks' neutral technical change and homotheticity have similar effects, these effects may be confused unless the two structural characteristics are isolated. That is, a test rejecting Hicks' neutrality while maintaining homotheticity may in fact be picking up nonneutral scale effects resulting from the possible misspecification of a nonhomothetic technology. Lopez could not reject the hypothesis of neutral technical change in a nonhomothetic generalized Leontief cost function of Canadian agriculture (11). But, by imposing homotheticity, he strongly rejected the hypothesis. A similar set of events occurred in Lau and Tamura's study of the Japanese petrochemical industry (9). More recently,

BEST COPY AVAILABLE

Antle (1) demonstrated the biases of homotheticity on factor demand elasticities as well as technical bias estimates for U.S. agriculture. To test for neutral technical change in the translog share equations, Hicks' neutrality implies:

$$B_{ij} = \frac{\partial(S_i/S_j)}{\partial T} = \frac{b_{it}}{S_i} - \frac{b_{jt}}{S_j} \gtrless 0 \qquad (11)$$

B_{ij} greater (less) than zero implies that technical change has resulted in using more (less) of s_i relative to s_j in production. These measures are also symmetric, but negative.

ESTIMATION AND RESULTS

The model was estimated with five variable inputs and a single aggregate output.[5/] The variable inputs include Divisia price indexes of capital services of durable equipment and farm-produced durables (inventories and breeding livestock), labor (hired, operator, and unpaid family), energy, materials (fertilizers, pesticides, miscellaneous intermediate inputs, and agricultural services), and land and structures. Output is a Divisia quantity index of gross output less farm-produced intermediate products. I estimated the system of factor share equations using full information maximum likelihood (FIML). Only n-1 share equations are estimated because estimating all equations results in a singular variance-covariance matrix. FIML estimation yields likelihood function values which one can use to perform likelihood ratio tests and in turn to perform various statistical tests on the model. The likelihood ratio is computed as the ratio of the maximum of the likelihood function under the null and alternate hypothesis. Minus twice the log of the likelihood ratio has an asymptotically Chi-square distribution where the degrees of freedom equal the number of restrictions imposed by the null hypothesis. Using this procedure, we test for the existence of homotheticity and neutral technical change. Table 1 shows the hypothesis test results. The appendix gives the estimated parameters and their standard errors.

In a nonhomothetic-nonneutral technical change (NHNNTC) version of the model, homotheticity was rejected at the 1-percent level of significance (LOS). I tested Hicks' neutrality in the nonhomothetic neutral technical change (NHNTC) version of the model against the alternate hypothesis, NHNNTC. NHNTC was also rejected at the 1-percent LOS. Finally, to demonstrate the significance of assuming homotheticity on tests for neutral technical change, I tested Hicks' neutrality in a homothetic version of the model, homothetic neutral technical change (HNTC) against the alternate hypothesis, homothetic nonneutral technical change (HNNTC). Hicks' neutrality was strongly rejected, far more than in the nonhomothetic model.

The nonhomothetic-nonneutral model was accepted as the final version. Price and substitution elasticities are calculated (table 2). Regularity conditions regarding the duality between the cost and production functions are satisfied with negative own-price elasticities (concavity of the cost function) and positive-estimated share equations (monotonicity).

The price elasticities indicate all inputs are relatively price-inelastic. The most price-elastic input is materials, -0.50, and the least price-elastic input is capital, -0.146. Energy, land, and labor have similar elasticities,

---

5/ The data were provided by Eldon Ball; a complete discussion of these data appear in (2).

BEST COPY AVAILABLE

Table 1--Chi-square statistics for hypothesis tests

Null hypothesis	Chi-square value	Critical values: Degrees of freedom	Critical values: Level of significance, 5 percent	Critical values: Level of significance, 1 percent
HNNTC 1/	43.974	4	9.48	13.27
NHNTC 2/	27.378	4	9.48	13.27
HNTC 3/	74.402	4	9.48	13.27

1/ Homothetic nonneutral technical change. 2/ Nonhomothetic neutral technical change. 3/ Homothetic neutral technical change.

Table 2--Own- and cross-price elasticities of factor demand and Allen partial elasticities of substitution (AES_{ij}) 1/

Measure	Capital	Labor	Energy	Materials	Land
Price elasticities of factor demand:					
Capital	-0.147	-0.172	0.048	0.233	0.037
	(.035)	(.041)	(.025)	(.031)	(.020)
Labor	-.171	-.337	.012	.393	.104
	(.041)	(.075)	(.008)	(.032)	(.006)
Energy	.167	.035	-.364	.164	-.002
	(.025)	(.015)	(.042)	(.010)	(.017)
Materials	.156	.264	.032	-.504	.052
	(.047)	(.047)	(.040)	(.058)	(.080)
Land	.057	.163	-.001	.121	-.341
	(.013)	(.004)	(.038)	(.034)	(.376)
AES:					
Capital	-.649	-.760	.213	.032	.163
	(.153)	(.180)	(.111)	(.139)	(.090)
Labor		-1.487	.053	.736	.461
		(.331)	(.225)	(.140)	(.027)
Energy			-5.569	2.513	.035
			(.646)	(.146)	(.265)
Materials				-1.495	.155
				(.171)	(.237)
Land					-2.353
					(2.597)

Blanks indicate the symmetry of AES; that is $AES_{ij} = AES_{ji}$.
1/ Elasticities evaluated at the point of approximation. Approximate standard errors are in parentheses.

BEST COPY AVAILABLE

-0.36, -0.34, and -0.34, respectively. Capital services appear to be more inelastic than land services. This finding suggests that purchases of capital services may be less active than those of land. The land price (implicit rental price) represents the services of all agricultural land. This price, therefore, includes land owned by the producer as well as rented land, which has become extremely important in determining total land services. Capital services include only own capital equipment, breeding livestock, and inventories, all of which include some adjustment costs associated with increases or decreases in demand in response to own-price changes. The rental of contract services, which includes capital services and contract labor, is included in the intermediate input category as purchased agricultural services. If hired capital services were included in the capital input, they would likely become more price elastic.

The AES's indicate that most inputs are substitutes. Positive (negative) AES's indicate substitutes (complements). Capital and labor as well as energy and land are complements.6/ The materials input is elastic with respect to all other inputs with values greater than 1.0. Materials and labor are significant substitutes, and materials and capital exhibit almost unitary substitution.

Upon rejecting homotheticity and Hicks' neutrality, we show the effects of scale and technical change on relative factor demand (tables 3 and 4). Because nonhomotheticity implies a nonlinear expansion path, the signs of the scale bias indicate the direction of factor bias. For example, we see that output expansion yields an expansion path which bends toward capital and away from labor. Technology also appears to bend toward energy and materials relative to capital and away from land relative to capital. Furthermore, we see the labor share is strongly reduced relative to all inputs. Energy and materials also increase with output relative to land.

These results are quite plausible and confirm Schertz's comments regarding the capitalization of agriculture, the changing input structure, and the scale of production (15). Many of these relationships, particularly those involving capital and labor, have been attributed to biased technical change. Most of these relationships still hold (table 4). Technical change is capital-using relative to labor and land. Neutral technical change appears to exist between capital and energy and between capital and materials. Labor input has been reduced relative to all factors because of technical change.

Furthermore, technical change is land-saving with respect to all inputs, except labor. These results are quite reasonable and are consistent with the findings of other studies. Weaver's study of U.S. wheat production, which also used Hicks' measure of technical bias, found similar factor bias (14, 18). Other studies that used the more conventional measure--that is, single-factor bias rather than relative-factor bias--found technical change to be capital-, fertilizer-, and land-using as well as labor-saving.7/

6/ The complementarity between capital and labor may seem unusual and may be the result of a specification problem. Specifically, the share equations are derived from a total variable cost function. Labor is largely comprised of self-employed and unpaid family labor and may be fixed or quasi-fixed inputs in the period that these data reflect. This condition suggests proper specification would be a shortrun variable cost function.

7/ Of course, differences in data, models, and estimation need to be considered.

BEST COPY AVAILABLE

Table 3--Factor biases due to nonhomotheticity 1/

Factor ratio	Labor	Energy	Materials	Land
Capital	1.997	-0.485	-0.564	0.756
	(.254)	(.187)	(.235)	(.309)
Labor		-2.483	-2.561	-1.241
		(.340)	(.308)	(.139)
Energy			-.0787	1.241
			(.253)	(.236)
Materials				1.320
				(.205)

Blanks indicate the symmetry of S_{ij}; that is, $S_{ij} = -S_{ji}$.
1/ Biases evaluated at the point of approximation. Approximate standard errors are in parentheses. Bias measures are symmetric but negative.

Table 4--Factor biases due to nonneutral technical change 1/

Factor ratio	Labor	Energy	Materials	Land
Capital	0.319	0.060	0.046	0.152
	(.061)	(.026)	(.043)	(.046)
Labor		-.259	-.273	-.167
		(.073)	(.093)	(.004)
Energy			-.013	.092
			(.025)	(.041)
Materials				.106
				(.025)

Blanks indicate the symmetry of B_{ij}; that is, $B_{ij} = -B_{ji}$.
1/ Biases evaluated at the point of approximation. Approximate standard errors are in parentheses. Bias measures are symmetric but negative.

EST COPY AVAILABLE

Note the bias in the technical change effects associated with the incorrect homothetic specification. Table 5 presents the estimates of biased technical change when homotheticity is imposed on the model. In all instances, the homotheticity specification leads to an upward bias in the technical change measure. These measures are necessarily biased because of the misspecification of the technology. By not including the influences of the nonneutral output effect, these measures indicate how the technical change bias can be overstated.

DECOMPOSITION OF RELATIVE FACTOR DEMAND

I have shown that several measurable effects influence relative factor demand; it would now be interesting to determine the extent of these separate effects. Kako demonstrated a method of decomposing the change in single-factor demands into output, substitution, and technical change effects (7). However, he assumed a CRS technology which, as already shown, restricts all input demands to be directly proportional to changes in output and which does not permit the differential effects of relative output elasticities. Kako examined only the influence of these three effects on single-factor demand. By contrast, I examine the effects on relative factor demand, which is in keeping with the true definitions of homotheticity and with Hicks' neutral technical change.

One can perform the decomposition analysis by totally differentiating the ratio of input-derived demand functions. By assuming producers exhibit cost-minimizing behavior, one can determine their set of equilibrium-factor demand equations as a function of outputs, the vector of input prices, and time. When these arguments are expressed in natural logarithms, the total derivative is :

$$d\log(x_i/x_j) = \frac{\partial \log(x_i/x_j)}{\partial \log Y} d\log Y + \Sigma_i \frac{\partial \log(x_i/x_j)}{\partial \log w_i} d\log w_i + \frac{\partial \log(x_i/x_j)}{\partial T} dT \qquad (12)$$

The first expression on the right side is the "output effect," that is, the measure of output bias on relative factor demand due to the nonhomothetic

Table 5--Technical change biases under homotheticity[1/]

Factor ratio	Labor	Energy	Materials	Land
Capital	0.646	-0.010	-0.085	0.380
Labor		-.656	-.731	-.265
Energy			-.074	.390
Materials				.465

Blanks indicate the symmetry of B_{ij}; that is, $B_{ij} = -B_{ji}$.

1/ Biases evaluated at the point of approximation. Standard errors were not calculated because of estimation bias. Bias measures are symmetric but negative.

BEST COPY AVAILABLE

production technology. The last expression is the "technical change effect," that is, Hicks' measure of nonneutral technical change. The second expression requires some explanation. This expression is the "total substitution effect," that is, the sum of the elasticities of substitution for each input pair. Because we are considering factor ratios, the substitution measures are calculated as Morishima elasticities of substitution (MES). The MES is one of three substitution elasticities measures generalized by Mundlak (12).[8/]

The most general elasticity is Hicks' direct elasticity of substitution, which is a two-factor, two-price elasticity of substitution. The MES is a two-factor, one-price measure, and the conventional AES is a one-factor, one-price measure. Koizumi (9) has written the MES as:

$$\sigma^M_{ij} = S_j(\sigma^A_{ij} - \sigma^A_{jj}) = \eta_{ij} - \eta_{jj} \qquad (13)$$

where the superscript A refers to Allen partial elasticity of substitution.

This expression for the MES makes its interpretation quite intuitive. Following Koizumi, we find that a decrease in price w_j, which makes x_j cheaper relative to x_i, will induce greater employment of x_j relative to x_i (assuming x_i and x_j are substitutes). But the relative increase in x_j may be overstated, as more x_j would be used simply because the input demand curve slopes downward. Therefore, one can derive the "net substitution effect" by subtracting the own-price demand effect. Thus, the MES can be defined as the substitution of x_j for x_i, given a change in w_j net of a change in x_j due to the pure own-demand effect. The result of this definition is that the MES is not symmetric. Furthermore, the MES does not yield the same results as the AES; that is, inputs may be classified as substitutes by AES and complements by MES (3). Finally, the MES can be calculated as the change in the x_i/x_j ratio with respect to a change in another price, w_k which is expressed as:

$$\sigma^M_{ijk} = S_k(\sigma^A_{ik} - \sigma^A_{jk}) = \eta_{ik} - \eta_{jk} \qquad (14)$$

Dividing equation (14) by the x_k cost share, S_k, yields the cross-elasticity of relative factor demand (5). Because the total substitution effect is the sum of the differences between various cross- and own-price elasticities and between the two cross-price elasticities (in equation (14)), the net effect depends on the relative magnitudes of these price elasticities. For example, the total substitution effect for nearly all input pairs is positive, implying they are "net" substitutes. I have calculated and summed all the MES's for the decomposition analysis which yield a "total substitution effect." The total substitution effect measures the total effects on equilibrium-relative factor demands of changes in factor prices with all other prices and output held constant. Using the parameters from the estimated system of share equations, one can calculate each of these effects. The output and total substitution effects are calculated explicitly and are subtracted from the observed growth in factor ratios, leaving the technical change effect as part of the residual. Table 6 shows both calculations and the percentage contributions of each effect for relative factor growth.

The capital-labor ratio increased 177 percent in 1948-79; the output effect contributed 70 percent to that change; and biased technical change

8/ For a good discussion and empirical comparison of these elasticities, see (3).

BEST COPY AVAILABLE

contributed 30 percent (table 6). The total substitution effect, while negative, had a value very near zero, implying that substitution between capital and labor due to relative prices was insignificant. This result is interesting because economists usually hypothesize that the increase in the relative price of labor spurred the technological developments, which increased the substitution of capital for labor. Although this hypothesis is not necessarily refuted, these results do suggest that autonomous technical change was more important to this change in the capital-labor ratio than was price-induced technical change. The ratios of capital to energy and materials have declined because of the effects of output and technical change. Technical change has been capital-saving relative to energy and materials. The implied increased use of materials relative to capital results from the increased productivity of agricultural chemicals, feeds, and seeds over this period. We see a positive output effect for capital relative to land, suggesting more capital services are needed per acre of land to increase output. We also have a capital-saving technical change, possibly because of tillage practices requiring fewer capital services.

Labor was the only input that declined significantly over this period, yielding a negative growth in the ratios of labor to all other inputs. The output effect and the technical change effect contributed significantly to these declines. The total substitution effect suggests that labor is a substitute for all other inputs including capital; that conclusion is asymmetric with the Allen elasticities of substitution, which suggest that capital and labor are complements.

The materials input is interesting because it has a uniform positive output effect; it is a "net" substitute with all other inputs, but the measure of the technical change bias suggests a materials-saving bias relative to all other inputs. Although the other two effects are quite plausible, it is surprising to see a materials-saving technical change; one would expect the opposite result. The percentage contribution for the residual/technical change effect is negative for materials in all cases, implying that the contribution of the other two effects (mainly the substitution effect) may be overestimated and thus overshadowed the technical change effects.

Finally, land's output effects are mostly negative and are symmetric to its corresponding pairs; however, the substitution and, therefore, the residual effects are not. Land is apparently a relatively elastic substitute with all other inputs.

Although the substitution and technical change effects are clearly important in determining the relative demand for inputs, the output effect is also important. It has had a positive and significantly differential effect on relative demands.

IMPLICATIONS

Many studies have attempted to measure structural change in U.S. agricultural production. Several have assumed a constant returns-to-scale technology and have, therefore, relegated all sources of structural change to price effects and technological progress. Although these two effects are clearly important, their effects may be over- or underestimated because of the exclusion of output effects. There is no a priori reason to believe that expansions or contractions of output should leave input ordering constant. Yet, this result is imposed by CRS assumptions.

BEST COPY AVAILABLE

BEST COPY AVAILABLE

Table 6--Decomposition of growth of relative factor demands: Output, total substitution, and technical change effects, 1948-79

Factor ratio	Annual growth	Nonhomotheticity/ output effect		Total substitution effect		Residual/technical change effect	
		Annual growth	Share	Annual growth	Share	Annual growth	Share
	Rate		Percent	Rate	Percent	Rate	Percent
Capital/labor	1.777	1.235	69.5	-0.005	-0.3	0.547	30.8
Capital/energy	-.119	-.300	251.6	.738	618.7	-.557	467.1
Capital/material	-.340	-.349	102.7	.199	-58.6	-.190	55.9
Capital/land	.860	.468	54.4	.762	88.6	-.370	-43.0
Labor/capital	-1.777	-1.235	69.5	.428	-24.1	-.970	54.6
Labor/energy	-1.896	-1.535	81.0	1.042	-54.9	-1.403	4.0
Labor/material	-2.116	-1.583	74.8	1.191	-56.3	-1.723	81.4
Labor/land	-.917	-.767	83.7	.958	-104.5	-1.108	120.8
Energy/capital	.119	.300	251.6	1.065	893.2	-1.246	-1044.8
Energy/labor	1.896	1.535	81.0	1.022	53.9	-.661	-34.9
Energy/material	-.220	-.049	22.1	.521	-236.6	-.693	314.6
Energy/land	.979	.768	78.4	1.227	125.3	-1.016	-103.8
Material/capital	.467	.349	74.6	1.491	319.2	-1.373	-293.8
Material/labor	2.116	1.583	74.8	1.757	83.0	-1.225	-57.9
Material/energy	.220	.049	22.1	1.412	641.1	-1.241	-563.2
Material/land	1.199	.816	68.1	1.631	136.1	-1.249	-104.1
Land/capital	-.326	-.468	143.4	1.454	-446.0	-1.312	402.6
Land/labor	.917	.767	83.7	1.818	198.2	-1.668	-181.9
Land/energy	-.979	-.768	78.4	1.287	-131.5	-1.499	153.1
Land/material	-1.199	-.816	68.1	1.024	-85.4	-1.407	117.3

An important implication of this study is that it shows the effect on relative input demands of a policy to reduce total production. For example, if market quotas were used with a targeted output reduction of 10 percent, the capital-land ratio would fall by 7.5 percent, implying the demand for capital services would decline or land services would either be constant or be used more extensively. The materials-land ratio would also fall by 13.2 percent, again implying that land would be used more extensively and that fewer material inputs would be used so as to minimize variable cost subject to the output constraint.

This decomposition analysis demonstrates how production costs will change with output-reducing policies. Although total costs may decline because of reduced production, costs will also change because of a change in the relative mix of inputs. The change in total costs will not be simply a change proportional to output. A simultaneous reordering of inputs occurs with the reduction or expansion of output. Changing the relative demand for inputs vis-a-vis output-reducing policies can also have a simultaneous effect on the prices of inputs, suggesting that input prices are endogenous in the context of econometric estimation.

An obvious extension of this study would be to apply this method to a multi-output model of production. Doing so would indicate not only the impact of output change on factor proportions but also its impact on relative output supplies. That is, we could determine how producers would reallocate inputs and outputs in response to output reduction programs and how this alteration would affect total costs.

These kinds of results are important and useful for policymaking. They point to the various types of assumptions we make when estimating producer behavior. Although the CRS assumption is theoretically quite tractable and is a simplifying assumption in empirical work, we need to be aware of the bias it may impose on the conclusions we draw from our investigations.

REFERENCES

(1) Antle, J.M. "The Structure of U.S. Agricultural Technology, 1910-78," American Journal of Agricultural Economics, Vol. 66, Nov. 1984, pp. 414-21.

(2) Ball, V.E. "Output, Inputs, and Productivity Measurement in U.S. Agriculture, 1947-79," American Journal of Agricultural Economics, Vol. 67, Aug. 1985, pp. 475-86.

(3) _____, R.E. Chambers. "An Economic Analysis of Technology in the Meat Products Industry," American Journal of Agricultural Economics, Vol. 64, Nov. 1982, pp. 699-709.

(4) Binswanger, H.P. "The Measurement of Technical Change Biases with Many Factors of Production," American Economic Review, Vol. 64, Dec. 1974, pp. 964-76.

(5) Hanoch, G. "Polar Functions with Constant Two Factor-One Price Elasticities," in Production Economics: A Dual Approach to Theory and Applications (ed. M. Fuss and D. McFadden). Amsterdam: North-Holland, 1978.

BEST COPY AVAILABLE

(6) Jorgenson, D.W., and Z. Griliches. "The Explanation of Productivity Change," Review of Economic Studies, Vol. 34, July 1967, pp. 249-84.

(7) Kako, T. "Decomposition Analysis of Derived Demand for Factor Inputs: The Case of Rice Production in Japan," American Journal of Agricultural Economics, Vol. 60, Nov. 1978, pp. 628-35.

(8) Koizumi, T. "A Further Note on Definition of Elasticity of Substitution in Many Input Cases," Metroeconomica, Vol. 28, Dec. 1976, pp. 152-55.

(9) Lau, L., and S. Tamura. "Economies of Scale, Technical Progress, and the Nonhomothetic Leontief Production Function: An Application to the Japanese Petrochemical Processing Industry," Journal of Political Economy, Vol. 80, Nov./Dec. 1972, pp. 1167-87.

(10) Lopez, R.E. "Estimating Substitution and Exparsion Effects Using a Profit Function Framework," American Journal of Agricultural Economics, Vol. 66, Aug. 1984, pp. 358-67.

(11) _____. "The Structure of Production and the Derived Demand for Inputs in Canadian Agriculture," American Journal of Agricultural Economics, Vol. 62, Feb. 1980, pp. 38-45.

(12) Mundlak, Y. "Elasticity of Substitution and the Theory of Derived Demand," Review of Economic Studies, Vol. 35, 1968, pp. 225-36.

(13) Ohta, M. "A Note on the Duality Between Production and Cost Functions: Rates of Returns to Scale and Rate of Technical Progress," Economic Studies Quarterly, Vol. 25, Dec. 1974, pp. 63-65.

(14) Ray, S. "A Translog Cost Function Analysis of U.S. Agriculture, 1939-77," American Journal of Agricultural Economics, Vol. 64, Aug. 1982, pp. 490-98.

(15) Schertz, L.P. "Farming in the United States," Structure Issues of American Agriculture. AER-438. U.S. Dept. of Agr., Econ. Stat. Coop. Serv., 1979.

(16) Shoemaker, R. "Total Factor Productivity and the Elasticity of Scale: An Analysis of U.S. Agriculture." Paper presented at the Southern Agricultural Economics Meetings, Feb. 1985.

(17) Sosin, K., and L. Fairchild. "Nonhomotheticity and Technological Bias in Production," Review of Economics and Statistics, Vol. 66, Feb. 1984, pp. 44-50.

(18) Weaver, R. "Multiple Inputs, Multiple Output Production Choices and Technology in the U.S. Wheat Region," American Journal of Agricultural Economics, Feb. 1983, pp. 45-55.

BEST COPY AVAILABLE

Appendix table--Coefficient estimates for translog share equations

Coefficient 1/	Estimated coefficient	Coefficient 1/	Estimated coefficient
a_K	0.2259	b_{EM}	-0.0113
	(.0032)		(.0032)
a_L	.2266	b_{EA}	-.0096
	(.0098)		(.0025)
a_E	.0630	b_{MM}	.0534
	(.0008)		(.0195)
a_M	.3373	b_{MA}	-.0218
	(.0091)		(.0116)
a_A	.1449	b_{AA}	.0745
	(.0068)		(.0545)
b_{KK}	.1418	b_{KY}	.0769
	(.0078)		(.0204)
b_{KL}	-.0900	b_{LY}	-.3756
	(.0092)		(.0589)
b_{KE}	-.0039	b_{EY}	.0540
	(.0016)		(.0107)
b_{KM}	-.0235	b_{MY}	.3050
	(.0106)		(.0656)
b_{KA}	-.0244	b_{AY}	-.0603
	(.0029)		(.0579)
b_{LL}	.0989	b_{KT}	.0258
	(.0170)		(.0038)
b_{LE}	-.0125	b_{LT}	-.0466
	(.0033)		(.0134)
b_{LM}	.0127	b_{ET}	.0035
	(.0107)		(.0015)
b_{LA}	-.0092	b_{MT}	.0228
	(.0009)		(.0129)
b_{EE}	.0373	b_{AT}	-.0056
	(.0028)		(.0092)

1/ K = capital; L = labor; E = energy; M = materials; A = land; Y = output; and T = time. Standard errors are in parentheses.

*U.S. Government Printing Office : 1986 -180-917/40671

BEST COPY AVAILABLE